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Yu. A. Dolgov, Yu F. Pogrennyak, N. A. Shugurova

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16. Abstract

The article continues a study of tektite, examining the composition and pressure of gases in occlusions of bediasite, darwinian, and Libyan glasses. Conclusions as to the origin of the gases is based on the differing compositions of the gases and base minerals, on the evident viscosity of the melt or re-melt stages, and on the pressure of the gases in the occlusions.

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THE COMPOSITION AND PRESSURES OF GASES IN OCCLUSIONS OF CERTAIN TEKTITES AND SILICA GLASSES†

Yu. A. Dolgov, Yu. F. Pogrennyak, N. A. Shugurova

Continuing the investigations of tektites begun earlier [1, 2], the authors analyzed the composition and pressure of gasses in individual gas acchisions in bediasite, a tektite of the Ivory Coast and in darwinian and Ribyan glasses. The samples for the investigation were courteously submitted by J. O'Keefe (NASA, U.S.A.), R. S. Clarke (National Museum, U.S.A.), I. Tseringer (Institute M. Planck, F.R.G.), R. O. Chalmers (Australian Museum) and L. G. Kvasha (Komitet po meteroritam, AN., U.S.S.R.). Flat parallel slices were cut from the samples for the study of the gas occlusions; the remaining material was used for conducting analyses of the chemical composition of the samples (%, see Table 1). The analyses were carried out on a quantity-meter by N. A. Arnautoviy and M. I. Zerkalova, oxides of the alkaline metals were defined on a flame photometer. /202*

The slices prepared from the samples were studied under a microscope. The Libyan glass contained large amounts of gas occlusions, basically, of a very irregular form, which bears witness to the considerable viscosity of the original melt.

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†Presented to the Academy by B. C. Soboleviy, April 2, 1970.

*Numbers in right hand margin indicate pagination of foreign text.

TABLE 1

Sample	SiO_4	Al_2O_3	Fe_{vol} (as Fe_2O_3)	CaO	MgO	K_2O	Na_2O	TiO_2	MnO	Σ
Tektite - bediasite	74.00	15.80	4.30	0.95	0.65	2.21	1.75	0.65	0.06	100.3
Tektite - Ivory Coast	68.60	14.14	6.23	1.09	4.24	2.33	2.77	0.57	0.09	100.0
Darwinian glass	86.00	8.96	1.90	0.20	0.81	1.66	0.14	0.40	0.01	100.8
Libyan glass	96.85	2.35	0.05	0.47	<0.01	0.13	0.19	0.04	0.02	100.1

The presence of large quantities of the characteristic inclusions of lechatelierite (Fig. 2) was noted; these are probably of relicts of remelted quartz grains, almost completely preserved in their primary form. The inclusions of lechatelierite were scattered in the basic mass of glass without order, but chains of these inclusions were encountered. The especially small fluidity of the lechatelierite formed during the remelt of the quartz grains proves that the temperature of the original melt was only slightly higher than the temperature of the quartz melt. A consequence of the insufficiently high temperature of the original melt is the high viscosity of the basic mass of glass, which finds its repercussion in the irregular form of the gas vacuoles. The lechatelierite of the Libyan glass, in contrast to all the investigations of our tektites, does not contain gas occlusions. The darwinian glass, in the slices investigated, was liberally impregnated with gas occlusions of spherical and ellipsoidal form (Fig. 3), often distributed in the form of a band. The sample of darwinian glass investigated shows a rather sharp fluid structure in the form of strips built up of glass of various indices of refraction and of several different colors; lechateleirite was not /203 detected. The bediarite had a small amount of gas vacuoles of globular form; lechatelierite was not found in it. In the Ivory Coast tektite, a large number of gas occlusions of globular form were detected, and also large inclusions of porous lechatelierite (Fig. 4). Unfortunately, due to technical reasons, the gases from the vacuoles of the lechatelierite of the Ivory Coast tektite were not analyzed.

[Translator's note: figure not legible.]

Fig. 1. Gas inclusions in Libyan glass. X50

[Translator's note: figure not legible.]

Fig. 2. Inclusion of lechatelierite in Libyan glass. X125

The studies of composition and pressures of gases in individual occlusions of tektites and silica glasses were carried out by ultra-microchemical volumetric methods, worked out in the laboratory of mineral-forming solutions of our institute. Analyses were done for $(H_2S + SO_2)_1$ CO_2, CO, O_2, and H_2; N_2 and rare gases were defined by group. In the $H_2S + SO_2$ group, NH_3, HCl, and HF were also possible, however, the last two were less probable. The sensitivity of the method is from 0.5 to 1%, the mean arithmetic error is 4%, and the mean squared error is 0.4%. A detailed description of the method is given in [3]. Results of the analyses of gases (% by volume) from the occlusions are given in Table 2.

[Translator's note: figure not legible.]

Fig. 3. Gas occlusions in Darwinian glass. X50

[Translator's note: figure not legible.]

Fig. 4. Inclusions of blistered lechatelierite in Ivory Coast tektite. X50

At the opening of all gas vacuoles, without exception, in the tektites and silica glasses (i.e., bringing their pressure to 1 atmosphere) the volumes of the gases locked in them sharply contracted. In the studies of the tektites (bediasite and tektites of the Ivory Coast), the volumes of the gases in the vacuoles decreased at opening from 437 to 1330 times. Still more strongly did the volumes of gases from the occlusions in Libyan glass contract: from 1850 to 2100 times. The volumes of gases from the opened vacuoles of the sample of Darwinian glass under study /204
decreased considerably less, from 13 to 30 times.

As we have already noted [2], the pressures of the gasses in the occlusions fall during the cooling of the glass, primarily for two reasons. On one hand, during fast cooling of a small mass of glass, its surface layer hardens first. With further cooling, a shrinking of the volume of the remaining layers of the internal parts of the glass compensates for the increase in volume of the vacuoles, in which the gas pressures correspondingly fall. On the other hand, with the cooling of these same gas filled vacuoles, their pressure also drops. However, it follows to consider that the first factor may have a significant effect only in the case of fast cooling of small masses of glass, since only in this case do the inner and outer portions of the glass not harden simultaneously. If this mass of glass is large, then the cooling will proceed slowly and the mass will harden uniformly throughout the volume. An analogous result is obtained for the slow cooling of a small mass of glass.

For a check of the accuracy of this proposition, we will analyze the pressures of gases in the occlusions in obsidian and technical glasses. It appears that the volumes of the gases in these lessen 3 to 5 times during opening, which almost completely can be explained by the decrease of pressure during cooling of the gas-filled vacuoles. It is understandable, then, that the influence of the first of the factors mentioned, on the lessening of pressures of the gases in the occlusions in obsidian and technical glasses, is insignificant, since they cool slowly, either due to large masses (obsidian), or as a result of the technological regime (technical glasses). Tektites, as stated, have small masses and, judging by the series of marks, harden very quickly [4], therefore, the lowering of the gas pressures in the occlusions in tektites must be especially significant on account of the expansion of the vacuoles during cooling of the glass.

We carried out the following experiment. A mixture of finely ground and carefully mixed chemicals (oxides of Si, Al, Ti and carbonates of Fe, Ca, Mg, K, Na, Mn) with ratios of these elements characteristic for tektites of the far-eastern field of distribution, was heated in a carundum crucible to 1800°, and the melt thus obtained was held at this temperature for a period of 4 hours. After this the crucible with the melt was taken out of the flame and cooled in air. From the resulting glass (the weight of which was approximately equal to 50 grams), slices were prepared. A study of the slices under the microscope showed that the glass contained a large quantity of spherical gas occlusions of diameters up to

1 mm. The results of the analyses of the composition and pressures of the gases from these occlusions are presented in Table 2. As for the composition of the gas from the vacuoles, there is a mixture CO_2 (formed during the breakdown of the carbonates) with N_2 and O_2. The oxygen and nitrogen have air-like ratios, attesting to their acquisiton from the atmosphere. With the opening of the occlusions, the volumes of the gases contracted in them from 525 to 3340 times, i.e., similar to the tektites and Libyan glasses investigated by us. Thus the experiment upholds the supposition that the low gas pressures observed in the vacuoles are explained by the fast cooling of the substances of the tektites and silica glasses.

According to the chemical composition, the gases from occlusions in bediasite and the Ivory Coast tektite, totally consist of CO_2. In the vacuoles of Libyan glass, H_2 and the N_2 + rare gases group are also found, besides CO_2. The vacuoles examined in Darwinian glass differ from the occlusions in bediasite, the Ivory Coast tektite and the Libyan glass, not only by a higher pressure of gases, but also by the composition of the gases. As in the glass fused by us, the gases from the occlusions in Darwinian glass consist of a mixture of CO_2 with N_2 and O_2.

As in composition, the Darwinian glass differs also in the pressures of the gases in the vacuoles from all the tektites and silica glasses studied by us.

A unique facet of this same type is that we found oxygen in its occlusions. Considering the ratio of the oxygen with nitrogen (about 1:4), it may be assumed that the vacuoles of Darwinian glass held air acquired from the earth's atmosphere. Also the contractions of the volumes of gases are unusually small during opening of the occlusions. All this, for the most part, naturally agrees with the supposition about the formation of Darwinian glass during the same remelt of the earth rock. At the same time, Libyan glass has much in common with the tektites concerning the pressures, and so also concerning the composition, of the gases in the vacuoles, despite the differences in the chemical mechanism composing their glasses. The practically complete identity of chemical composition of the quartz grains underlying it [5] and the very low gas pressure in the occlusions speak for the fact that it was formed during a remelt of sand by the energy of some exceedingly powerful explosion with a subsequent fast cooling of the drops of melt thrown into the atmosphere. The tektites were probably formed in an analogous manner. It appears that the differences lie only in the energies of the explosions and in the originating material, a fact that finds its repercussions in the dimensions of the field of distribution, in the chemical compositions, and in the temperature of formation of the glasses. The explosive origin of the tektites is also supported by the presence of keosite [6]. This mineral is formed at very high pressures and is found on earth, excluding the products of nuclear explosions, only in the rocks from meteor craters. This last requires that we consider in detail the most likely sources of energy necessary for the formation of tektites and Libyan glass, explosions during the impact of meteors or similar bodies on the surface of the earth, having sufficiently high velocities and masses.

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TABLE 2

Sample	Contraction of volume of gases after opening, multiplicity factor	CO_2	Sample	Contraction of volume of gases after opening, multiplicity factor	CO_2	C_2	H_2	N_2 + rare gases
Tektite-	437	100.0	Darwinian	13	21.8	16.0	0.0	62.2
bediasite	917	100.0	Glass	23	24.2	15.0	0.0	60.8
	572	100.0		16	27.8	15.0	0.0	57.2
	527	100.0		30	25.8	15.0	0.0	59.2
Tektite	1045	100.0		16	38.4	12.0	0.0	49.6
of Ivory	1330	100.0	Libyan	2100	45.5	0.0	22.8	34.7
Coast	456	100.0	Glass	1850	47.0	0.0	28.0	25.0
				2060	46.0	0.0	25.5	28.5
			Arti-	525	12.1	17.5	0.0	70.4
			ficial	637	87.0	2.6	0.0	40.4
			Glass	3340	43.2	11.0	0.0	45.8
				1352	44.3	11.3	0.0	44.4
				1410	43.4	11.0	0.0	45.6

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